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A DIVISION OF NORTH AMERICAN AVIATION, INC.

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TO S. F. Iacobellis DEPT. 569-190  
FROM R. V. Burry DEPT. 569-193  
PHONE 3444 DATE 21 November 1963  
SUBJECT Review of NASA Contract, NAS 9-1729, "High Performance Apollo Propulsion System Study", Phase I

The enclosed report presents a review of the subject contract through 1 December 1963.

R. V. Burry C 65-1593  
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RVB:so

CLASSIFICATION CHANGE

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LAP 63-755-A

REVIEW OF NASA CONTRACT

NAS 9-1729

HIGH PERFORMANCE APOLLO  
PROPULSION SYSTEM STUDY

[U]

~~DECLASSIFIED AT 3 YEAR INTERVALS~~  
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1 December 1963

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**ROCKETDYNE**  
A DIVISION OF NORTH AMERICAN AVIATION INC.

REPORT OF INVESTIGATION, INC 2-1782

"HIGH PERFORMANCE APOLLO PROPULSION SYSTEM STUDY", PHASE I

INTRODUCTION

The enclosed charts present a review to date of the Phase I investigations conducted on the "High Performance Apollo Propulsion System Study". The purpose of this study is to evaluate the use of high-energy propellants and advanced propulsion-system concepts to increase the landed-payload capability of the Apollo vehicle. The program is divided into two phases. In Phase I of this program, propellants and propulsion systems that will be operational by 1970 are considered, while in Phase II systems are considered for a 1975 operational date.

Each phase of the program is composed of five tasks: I. Propellant Survey--review of propellant and candidate propellant selection, II. Propellant Selection analysis of propulsion systems using the candidate propellants, III. System Design--vehicle and propulsion system design for a selected propellant combination, IV. Reliability Analysis--reliability analysis of the propulsion system design, V. Development Requirements--description of the development requirements necessary to realize the operational systems.

In this review three areas are described. First, the Apollo mission and the individual Apollo propulsion systems are described. Second, the Propellant Survey (Task I) is briefly reviewed and the propellant combination candidates listed for both Phase I (1970) and Phase II (1975). Third, the investigations of the Phase I propellant candidates as used in propulsion systems are described and comparisons made between the various candidates. Based upon these comparisons, the propellant combination best suited for use in an advanced Apollo propulsion system was selected.

N A S A    H I G H    P E R F O R M A N C E    A P O L L O    C O N T R A C T

Purpose:

Increase the landed Payload

Phase:  
1970      High Energy Propellants; Minimum Design Changes  
1975      High Energy Propellants; Advanced Propulsion Designs

- |      |     |                                 |
|------|-----|---------------------------------|
| Task | I   | Propellant Survey               |
|      | II  | Propulsion Analysis             |
|      | III | Vehicle Design                  |
|      | IV  | Reliability Analysis            |
|      | V   | Recommended Development Program |

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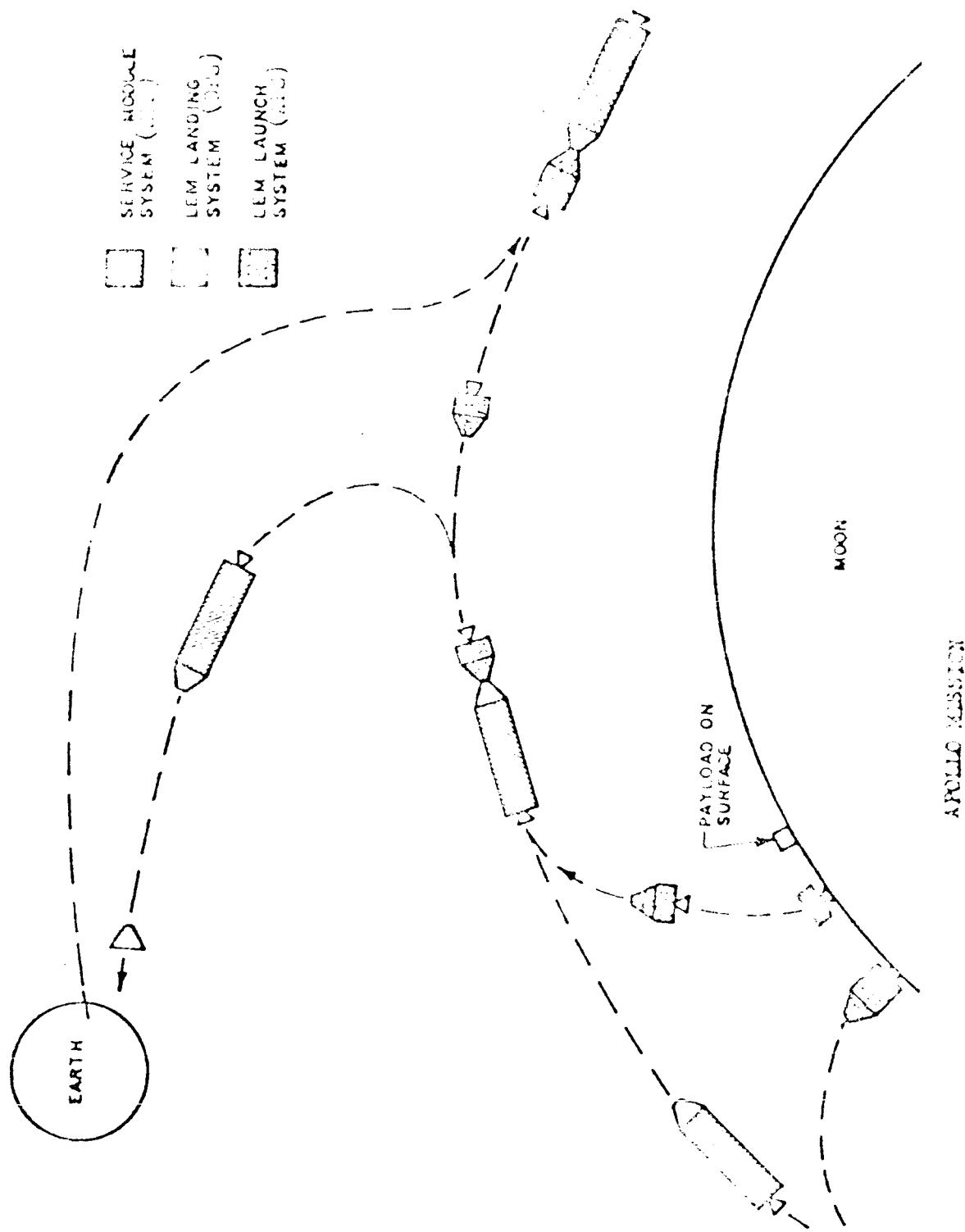
## APOLLO MISSION AND PROPULSION

### SYSTEM DESCRIPTION

The Apollo mission operational schedule, and propulsion systems are briefly described in order to define the basis for the high performance Apollo propulsion system study. In the mission description, the maneuvers performed by the three propulsion systems (Service, Descent, and Ascent) are defined. From this an operational schedule, presenting the number and duration of engine operations, was derived. Design parameters for each of the current  $N_2O_4/50-50$  propellant propulsion systems are briefly described, and the Service Module and LEM stage layouts are shown.

**PROTOTYPING SYSTEM.**

- User friendly
- Service module
- Full system management



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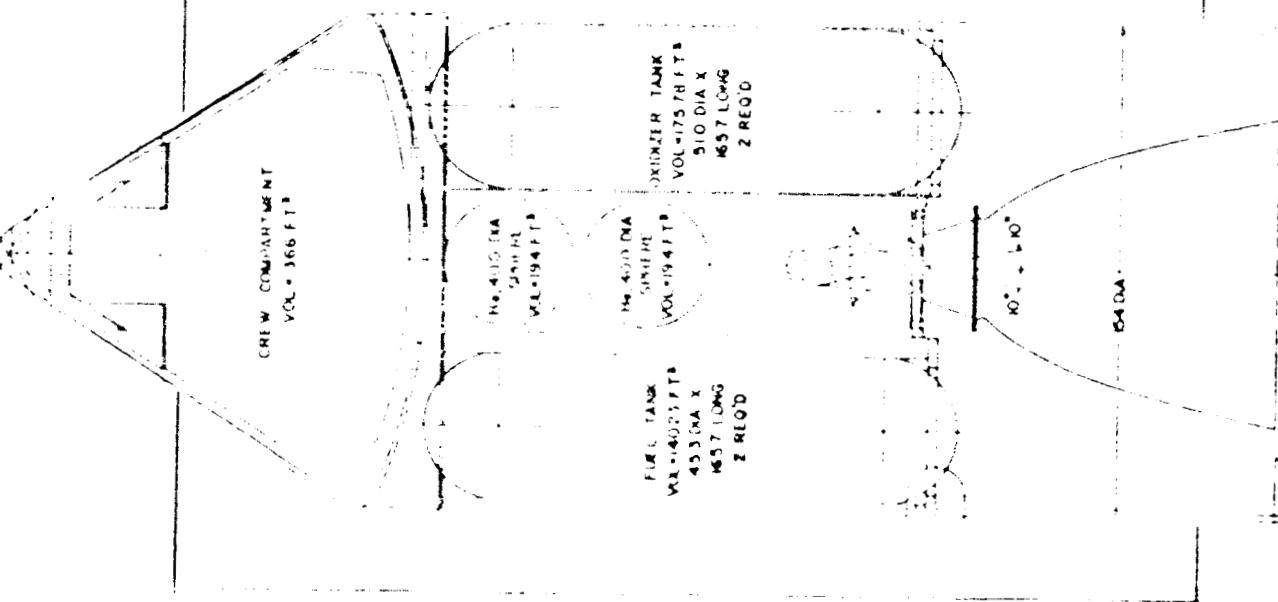
## APOLLO Navigation System OPERATING SCHEME

| Module<br>Operation              | Service           |                 | Descent           |                 | Ascent            |                 |
|----------------------------------|-------------------|-----------------|-------------------|-----------------|-------------------|-----------------|
|                                  | No. of<br>Firings | Firing*<br>Time | No. of<br>Firings | Firing*<br>Time | No. of<br>Firings | Firing*<br>Time |
| Attitude<br>Holding              | 3                 | 135 sec         | 3                 | 135 sec         | 3                 | 135 sec         |
| Midcourse<br>Corrections         | 3-4               | 30              | -                 | -               | -                 | -               |
| Orbit<br>Establishment           | 1                 | 370             | -                 | -               | -                 | -               |
| Orbit<br>Correction              | 1                 | 10              | -                 | -               | -                 | -               |
| Establish<br>Elliptical<br>Orbit | -                 | -               | 1                 | 30              | -                 | -               |
| Correction                       | -                 | -               | 1                 | 5               | -                 | -               |
| Landing                          | -                 | -               | 1                 | 410             | -                 | -               |
| Hover**                          | -                 | -               | 0                 | 120             | -                 | -               |
| Takeoff                          | -                 | -               | -                 | -               | 1                 | 380             |
| Recovery                         | 2                 | 20              | -                 | -               | 2                 | 20              |
| Depart Orbit                     | 1                 | 160             | -                 | -               | -                 | -               |
| Midcourse<br>Corrections         | 3-4               | 30              | -                 | -               | -                 | -               |
| No. Starts                       |                   | 13              |                   | 3               |                   | 3               |

\* Approximate Values Based on Nvg04/50-50

\*\*10:1 Thrust Ratio; Confined with the Landing Operation

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A P C L I Q S E R V I C E  
M O D U L E

22,000  
LIT/SEC

51,200  
LIT/sec  
(approx)  
100,000  
LIT/sec  
2.2

100,000  
LIT/sec  
Specific Impulse

CREW COMPARTMENT  
VOL = 166 FT<sup>3</sup>

FUEL TANK  
WAL 4031 FTs  
453 DIA X  
457 LONG  
2 RELOAD

OXIDIZER TANK  
WAL 4031 FTs  
453 DIA X  
510 DIA X  
457 LONG  
2 RELOAD

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~~COMINT~~

PROPELLANT SURVEY

The results of the Propellant Survey (Task I) are briefly reviewed. The purpose of the Propellant Survey was to establish the potential propellant candidates for the advanced Apollo propulsion system. The 1970 (Phase I) and 1975 (Phase II) Propellant Survey results are both presented in this report. This survey considered the performance, physical characteristics, and availability of a large number of propellants, and indicated, in a general manner, the effect on the propulsion system design and operation. Four candidates were selected which could be developed into operational systems by 1970 and six substitutes are presented for 1975 operational systems.

1212 Computer graphics

1210 Computer graphics

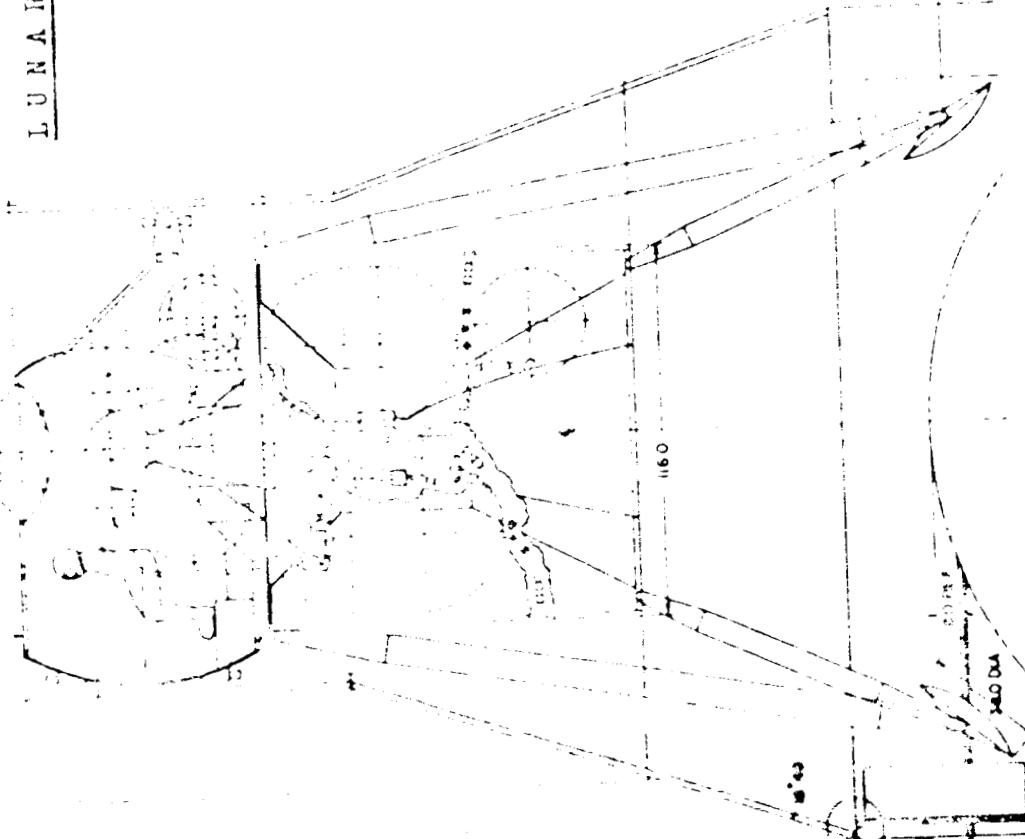
Hightech Research Institute Computer Graphics

Computer graphics Survey and Computer graphics

EDUTELNET SURVEY

MAX T

LUNAR EXCURSION MODULE



P R O P E L L A N T S    S E R V I C E    G R U C U N D    R O S I D S

Consider Synthesized Propellants only

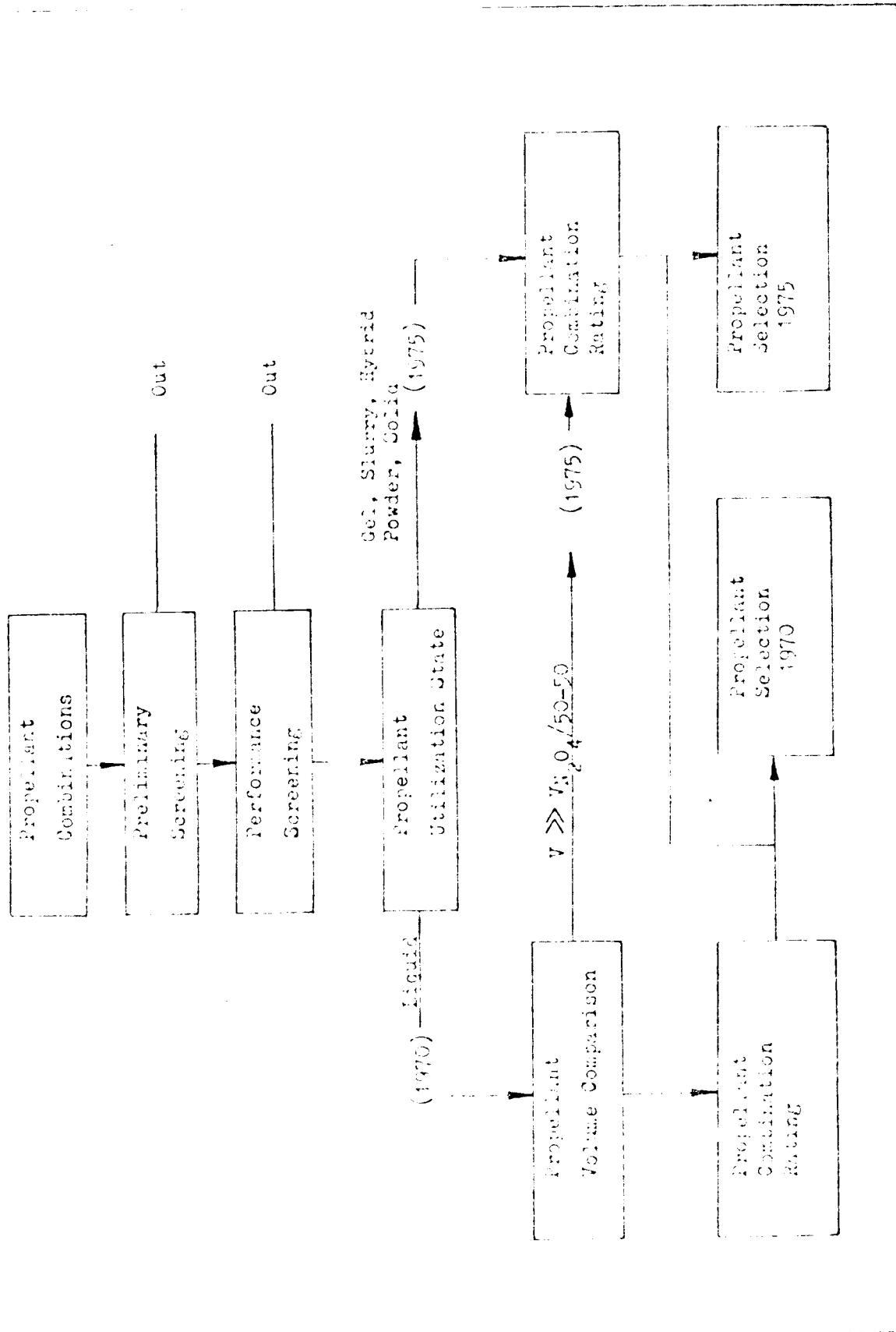
Propellants Must Provide an Increase In Payload  
1970 Systems

1. Emphasize Minimum Design Changes
2. Current NASA Service Module Design Concept
3. Current Grumman LEM Design Concept
4. Consider Only Liquid Propellants

1975 Systems

1. No Design Change Limitations
2. Life Support Capsules are Fixed
3. Solid, Hybrid and Slurry Propellants May be Considered

PROPELLANT SURVEY FLOW CHART



PROBLEMS AND LISTINGS

卷之二

卷之三

### 1970 PRE-ELIMINAT COMBINATION RATING

| Major Factor             | Minor Factor                 | Relative Factor | Relative Score | Relative Factor             | Relative Score |
|--------------------------|------------------------------|-----------------|----------------|-----------------------------|----------------|
| I. Performance           | A. Relative Payload          | 1.0             | 1.0            | B. Relative Volume          | 0.6            |
|                          | C. Experience                |                 |                | D. Operation Simplicity     | 2.0            |
| II. Reliability          | E. Two-Point Transfer Factor | 0.5             | 0.5            | F. Propellant Sensitivity   | 0.4            |
|                          | G. Propellant Compatibility  |                 |                | H. Igniter Igniter Coupling | 1.5            |
| III. Operational Aspects | I. Propellant Storage Intake | 0.5             | 0.5            | J. Igniter Igniter Coupling | 1.5            |
|                          | K. Igniter Igniter Coupling  |                 |                | L. Igniter Igniter Coupling | 2.0            |
| IV. Development Risk     | M. Igniter Igniter Coupling  | 0.3             | 0.3            | N. Igniter Igniter Coupling | 2.0            |
|                          | O. Igniter Igniter Coupling  |                 |                | P. Igniter Igniter Coupling | 2.0            |
| V. Toxicity              | Q. Igniter Igniter Coupling  | 0.2             | 0.2            | R. Igniter Igniter Coupling | 2.0            |
|                          | S. Igniter Igniter Coupling  |                 |                | T. Igniter Igniter Coupling | 2.0            |
|                          | U. Igniter Igniter Coupling  |                 |                | V. Igniter Igniter Coupling | 2.0            |
|                          | W. Igniter Igniter Coupling  |                 |                | X. Igniter Igniter Coupling | 2.0            |
|                          | Y. Igniter Igniter Coupling  |                 |                | Z. Igniter Igniter Coupling | 2.0            |

REVIEW OF RECENT WORK ON POLYMER SYSTEMS

| <u>Compound</u>   | <u>Ref.</u> | <u>Author(s)</u>                      | <u>Source</u>                                     |
|---|-------------|---------------------------------------|---|
| 1. $\text{P}_2$   | 1.          | $\text{KH}_2$                         | 1. $\text{NaH}/\text{NH}_4\text{Cl}$ $\text{O}_4$ |
| 2. $\text{Si}_2\text{F}_2$                                  | 2.          | $\text{NaF}_4$                        | 2. $\text{Na}/\text{NH}_4\text{Cl}$ $\text{O}_4$  |
| 3. Compound A   | 3.          | $\text{LiH}_2$                        | 3. $\text{Be H}_2$                                |
| 4. $\text{Si}_2\text{Br}_2$                                 | 4.          | $\text{LiH}_2$                        | 4. $\text{Al H}_3$                                |
| 5. $\text{Si}_2\text{C}_2\text{F}_2$                        | 5.          | $\text{CH}_4$                         | 5. Li   |
| 6. $\text{C}_2$   | 6.          | $\text{C}_2\text{H}_6$                | 6. Li H   |
| 7. $\text{LiO}_2$ (35-percent)                              | 7.          | $\text{KBr}$                          | 7. $\text{KBr}$                                   |
| 8. $\text{NaC}_2$   | 8.          | $\text{NaH}_2$                        | 8. $\text{NaH}_2$                                 |
| 9. $\text{Si}_2\text{O}_3$                                  | 9.          | $\text{NaH}_2$                        | 9. $\text{NaH}_2$                                 |
| 10. $\text{Si}_2\text{O}_2$                                 | 10.         | Uganda A-5                            | 10. Uganda A-5                                    |
| 11. $\text{Si}_2\text{O}_3$                                 | 11.         | Uganda B-3                            | 11. Uganda B-3                                    |
| 12. $\text{Al}_2\text{P}_2$                                 | 12.         | H                                     | 12. H   |
| 13. $\text{C}_2\text{H}_3$                                  | 13.         | $\text{NaH}_2/\text{CDMH}$            | 13. $\text{NaH}_2/\text{CDMH}$                    |
| 14. $\text{Al}_2\text{O}_3$                                 | 14.         | Ag bromoiodide P                      | 14. Ag bromoiodide P                              |
| 15. $\text{NaCl}$   | 15.         | Hydride                               | 15. Hydride                                       |
| 16. NUCLE 2A  | 16.         | $\text{CaH}_2\text{BaH}_2\text{Li}_3$ | 16. $\text{CaH}_2\text{BaH}_2\text{Li}_3$         |
| 17. $\text{MgNa}$   | 17.         | $\text{AlH}_3$ **                     | 17. $\text{AlH}_3$ **                             |
| 18. $\text{MgNa}$   | 18.         | $\text{BeH}_2$ **                     | 18. $\text{BeH}_2$ **                             |
| 19. $\text{Ca}_2\text{P}_2/\text{Cl}_2\text{C}_2\text{F}_2$ | 19.         | $(\text{CH}_2)_x$ **                  | 19. $(\text{CH}_2)_x$ **                          |
| 20. $\text{NaCa}$   | 20.         | Li **                                 | 20. Li **   |
| 21. $\text{Li}_2\text{H}_4$ *                               | 21.         | Li H **                               | 21. Li H **                                       |
|   |             | ** with $\text{D}_2\text{O}_2$        | ** with $\text{D}_2\text{O}_2$                    |
|   |             | *** 49/75 Systems Only                | *** 49/75 Systems Only                            |
|   |             | **** Al ***                           | **** Al ***                                       |

CONTINUATION

**1975 Evaluation of Solid Rocket Propellants**

**Scoring Factors**      **Rating**      **Rating Factor**

| <b>Scoring Factor</b>    | <b>Rating</b> | <b>Rating Factor</b>          |
|--------------------------|---------------|-------------------------------|
| I. Performance           | 1.0           | A. Relative Payload           |
| II. Reliability          | 0.25          | A. Propellant Transfer Method |
|                          |               | B. Operation Simplicity       |
| III. Operational Aspects | 0.6           | A. Operation Simplicity       |
|                          |               | B. Ignition Sensitivity       |
|                          |               | C. Propellant Thermal Storage |
|                          |               | D. Thrust Chamber Cooling     |
| IV. Development Mass     | 0.20          | A. Thrust Chamber Cooling     |
|                          |               | B. Toxicity                   |
|                          |               | C. Propellant Transfer Method |
| V. Launch Ignition Ease  | 0.15          | A. Launch Storage Method      |
|                          |               | B. Toxicity                   |

1970 PROFLAME CONSUMPTION OVERALL RATING

|   |     |  |     |  |     |                                      |     |
|---|-----|--|-----|--|-----|--------------------------------------|-----|
| $\text{O}_2/\text{H}_2\text{A}_4$               | 225 | $\text{O}_2/\text{H}_2\text{A}_6$            | 131 | $\text{O}_2/\text{C}_2\text{H}_6$              | 171 | $\text{O}_2/\text{CH}_3\text{Cl}_2$  | 153 |
| $\text{O}_2/\text{H}_2\text{C}_2\text{H}_4$     | 224 | $\text{O}_2/\text{H}_2\text{C}_2\text{H}_6$  | 179 | $\text{O}_2/\text{C}_2\text{H}_5\text{Cl}_2$   | 170 | $\text{O}_2/\text{CH}_3\text{Cl}_2$  | 157 |
| $\text{NO}_x/\text{H}_2\text{C}_2\text{H}_4$    | 218 | $\text{NO}_x/\text{H}_2\text{C}_2\text{H}_6$ | 179 | $\text{N}_2^3/\text{C}_2\text{H}_5\text{Cl}_2$ | 163 | $\text{NO}_x/\text{CH}_3\text{Cl}_2$ | 156 |
| $\text{O}_2/\text{H}_2\text{C}_2\text{H}_4$     | 216 | $\text{O}_2/\text{H}_2\text{C}_2\text{H}_6$  | 179 | $\text{NO}_x/\text{C}_2\text{H}_5\text{Cl}_2$  | 167 | $\text{NO}_x/\text{CH}_3\text{Cl}_2$ | 155 |
| $\text{O}_2/\text{H}_2\text{C}_2\text{H}_6$     | 209 | $\text{O}_2/\text{H}_2\text{C}_2\text{H}_6$  | 178 | $\text{NO}_x/\text{C}_2\text{H}_5\text{Cl}_2$  | 166 | $\text{O}_2/\text{CH}_3\text{Cl}_2$  | 153 |
| $\text{NO}_x/\text{H}_2\text{C}_2\text{H}_6$    | 205 | $\text{O}_2/\text{H}_2\text{C}_2\text{H}_6$  | 178 | $\text{NO}_x/\text{C}_2\text{H}_5\text{Cl}_2$  | 166 | $\text{O}_2/\text{CH}_3\text{Cl}_2$  | 153 |
| $\text{NO}_x/\text{H}_2\text{C}_2\text{H}_6-50$ | 206 | $\text{O}_2/\text{H}_2\text{C}_2\text{H}_6$  | 177 | $\text{NO}_x/\text{C}_2\text{H}_5\text{Cl}_2$  | 165 | $\text{NO}_x/\text{CH}_3\text{Cl}_2$ | 154 |
| $\text{O}_2/\text{H}_2\text{C}_2\text{H}_6-50$  | 204 | $\text{O}_2/\text{H}_2\text{C}_2\text{H}_6$  | 177 | $\text{NO}_x/\text{C}_2\text{H}_5\text{Cl}_2$  | 165 | $\text{NO}_x/\text{CH}_3\text{Cl}_2$ | 153 |
| $\text{NO}_x/\text{H}_2\text{C}_2\text{H}_6$    | 200 | $\text{O}_2/\text{H}_2\text{C}_2\text{H}_6$  | 177 | $\text{NO}_x/\text{C}_2\text{H}_5\text{Cl}_2$  | 165 | $\text{NO}_x/\text{CH}_3\text{Cl}_2$ | 154 |
| $\text{O}_2/\text{H}_2\text{C}_2\text{H}_6-1$   | 199 | $\text{O}_2/\text{H}_2\text{C}_2\text{H}_6$  | 176 | $\text{O}_2/\text{C}_2\text{H}_4$              | 164 | $\text{O}_2/\text{CH}_2\text{Cl}_2$  | 153 |
| $\text{NO}_x/\text{H}_2\text{C}_2\text{H}_6$    | 199 | $\text{O}_2/\text{H}_2\text{C}_2\text{H}_6$  | 174 | $\text{O}_2/\text{C}_2\text{H}_4$              | 162 | $\text{O}_2/\text{CH}_2\text{Cl}_2$  | 153 |
| $\text{O}_2/\text{H}_2\text{C}_2\text{H}_6-1$   | 190 | $\text{O}_2/\text{H}_2\text{C}_2\text{H}_6$  | 173 | $\text{O}_2/\text{C}_2\text{H}_4$              | 162 | $\text{NO}_x/\text{CH}_3\text{Cl}_2$ | 153 |
| $\text{O}_2/\text{C}_2\text{H}_4$               | 169 | $\text{O}_2/\text{C}_2\text{H}_4$            | 172 | $\text{O}_2/\text{C}_2\text{H}_4$              | 162 | $\text{O}_2/\text{C}_2\text{H}_6$    | 152 |
| $\text{O}_2/\text{C}_2\text{H}_6$               | 167 | $\text{O}_2/\text{C}_2\text{H}_6$            | 172 | $\text{NO}_x/\text{C}_2\text{H}_4$             | 161 | $\text{NO}_x/\text{CH}_2\text{Cl}_2$ | 152 |
| $\text{O}_2/\text{C}_2\text{H}_6-50$            | 165 | $\text{O}_2/\text{C}_2\text{H}_6$            | 172 | $\text{NO}_x/\text{C}_2\text{H}_4$             | 159 | $\text{NO}_x/\text{CH}_2\text{Cl}_2$ | 150 |
| $\text{O}_2/\text{H}_2\text{C}_2\text{H}_4$     | 162 | $\text{O}_2/\text{H}_2\text{C}_2\text{H}_4$  | 171 | $\text{O}_2/\text{C}_2\text{H}_6$              | 158 | $\text{O}_2/\text{CH}_2\text{Cl}_2$  | 150 |
| $\text{O}_2/\text{H}_2\text{C}_2\text{H}_4$     | 161 | $\text{O}_2/\text{H}_2\text{C}_2\text{H}_4$  | 171 | $\text{O}_2/\text{CH}_2\text{Cl}_2$            | 157 | $\text{O}_2/\text{CH}_2\text{Cl}_2$  | 150 |

**1975 PROPELLANT COMBINATIONS OVERALL RATING**

**Bipropellants**

| <u>Propellant Combination</u>                  | <u>Rating</u> | <u>Propellant Combination</u>                   | <u>Rating</u> |
|--|---------------|---|---------------|
| $\text{N}_2\text{O}_4/\text{CH}_4$             | 2.53          | $\text{F}_2/\text{CH}_4$                        | 1.97          |
| $\text{N}_2\text{O}_4/\text{H}_2$              | 2.79          | $\text{N}_2\text{O}_4/\text{N}_2\text{H}_4$     | 1.94          |
| $\text{N}_2\text{O}_4/\text{H}_2\text{O}$      | 2.92          | $\text{OP}_2/\text{CH}_4$                       | 1.90          |
| $\text{NLOX}(\text{C}-10)/\text{CH}_4$         | 2.90          | $\text{OP}_2/\text{N}_2\text{O}$                | 1.80          |
| $\text{N}_2/\text{CH}_4$                       | 2.91          | $\text{NLOX}(\text{C}-10)/\text{C}_2\text{H}_6$ | 1.76          |
| $\text{NLOX}(\text{C}-10)/\text{N}_2\text{O}$  | 2.94          | $\text{OP}_2/\text{CH}_4$                       | 1.66          |
| $\text{N}_2/\text{H}_2$                        | 2.97          | $\text{CP}_2/\text{RP}-1$                       | 1.65          |
| $\text{N}_2/\text{Hypalon}$                    | 2.97          | $\text{F}_2/\text{Hypalon}$                     | 1.65          |
| $\text{F}_2/\text{N}_2/\text{H}_2$             | 2.97          | $\text{CP}_2/\text{N}_2\text{H}_4$              | 1.64          |
| $\text{N}_2\text{O}_4/\text{H}_2$              | 2.99          | $\text{N}_2\text{O}_4/\text{C}_2\text{H}_6$     | 1.64          |
| $\text{CP}_2/\text{C}_2\text{H}_6/\text{CH}_2$ | 2.95          | $\text{OP}_2/\text{CH}_4$                       | 1.63          |
| $\text{F}_2/\text{N}_2\text{O}$                | 2.94          | $\text{CP}_2/\text{CH}_4$                       | 1.61          |
| $\text{CP}_2/\text{H}_2$                       | 2.94          | $\text{OP}_2/\text{Hypalon}$                    | 1.61          |
| $\text{F}_2/\text{CH}_4$                       | 2.93          | $\text{OP}_2/\text{Hypalon}$                    | 1.61          |
| $\text{NLOX}(\text{C}-10)/\text{CH}_4$         | 2.97          | $\text{F}_2/\text{CH}_4$                        | 1.61          |
| $\text{CP}_2/\text{CH}_4$                      | 2.92          | $\text{N}_2\text{O}_4/\text{F}_2$               | 1.76          |
| $\text{NLOX}(\text{C}-10)/\text{CH}_4$         | 2.91          | $\text{CP}_2/\text{Hydroxid-P}$                 | 1.76          |
| $\text{C}_2\text{H}_2/\text{H}_2$              | 2.90          | $\text{FLOX}(\text{C}-70)/\text{CH}_4$          | 1.71          |

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1975 Photo-Island Selection Overview

Individual Anisotropy

| Reaction                                      | Anisotropic<br>Relative<br>Percent | Improvisant<br>Relative<br>Percent | Improvisant<br>Percent |
|---|------------------------------------|------------------------------------|------------------------|
| $\text{C}_2\text{H}_2 + \text{H}_2\text{O}_2$ | 1.6                                | 6.2                                | 12.8                   |
| $\text{C}_2\text{H}_2 + 2\text{eH}_2$         | 6.3*                               | 9.6                                | 2.7                    |
| $\text{C}_2\text{H}_2 + \text{He}$            | 9.6                                | 9.4                                | 1.9                    |
| $\text{C}_2\text{H}_2 + \text{ArHe}$          | 10.0                               | 7.0                                | 1.0                    |
| $\text{C}_2\text{H}_2 + \text{Ar}$            | 9.6*                               | 8.0                                | 1.6                    |
| $\text{C}_2\text{H}_2 + \text{He}$            | 9.4*                               | 8.0                                | 2.0                    |
| $\text{C}_2\text{H}_2 + \text{ArHe}$          | 9.0                                | 2.4                                | 0.4                    |
| $\text{C}_2\text{H}_2 + \text{Ar}$            | 6.7*                               | 6.7                                | 0.9                    |
| $\text{C}_2\text{H}_2 + \text{He}$            | 5.8*                               | 5.7                                | 0.7                    |
| $\text{C}_2\text{H}_2 + \text{ArHe}$          | 5.7                                | 5.7                                | 0.5                    |
| $\text{C}_2\text{H}_2 + \text{He}$            | 5.7                                | 5.0                                | 1.2                    |
| $\text{C}_2\text{H}_2 + \text{Ar}$            | 5.6*                               | 21.6                               | 1.6                    |
| $\text{C}_2\text{H}_2 + \text{ArHe}$          | 5.5                                | 2.4                                | 0.4                    |
| $\text{C}_2\text{H}_2 + \text{Ar}$            | 5.5                                | 0.6                                | 0.1                    |
| <hr/> <i>*Estimated</i>                       |                                    |                                    |                        |

**PROPELLANT COMBINATION CANDIDATE SELECTION CRITERIA**

**1970**

- Different Oxidizer Characteristics
- High Overall Rating
- High Performance Rating

**1975**

Payload Range Similar to 1970 Candidates

Physical States Represented

- 3 Liquid Propellant Systems
- 4 Solid Systems
- 2 Metallic Additive Systems

Solids Eliminated Because of Limited  
Restart Technology

3 3 3 3 3 3 3 PAO P E Z L A N G S

1700

$\text{P}_2/\text{H}_2\text{S}_2$ ,  $\text{NH}_3$

$\text{P}_{20}\text{H}_2\text{S}_2)/\text{NH}_3$

$\text{O}_2/\text{CH}_4$ ,  $\text{D}_2\text{H}_6$ ,  $\text{NH}$

comp (A) /  $\text{N}_2\text{O}_4$

1900

$\text{P}_2/\text{H}_2$

test 1970 Combination

$\text{O}_2/\text{C}_2\text{H}_2\text{B}_{10}\text{H}_{13}$

$\text{P}_2/\text{NH}_2$

$\text{O}_2/\text{H}_2 + \text{Ne}$

$\text{P}_2/\text{NH} + \text{NH}_2$

Oct 1970 - 2000 hrs

## ADVANCED APOLLO

## 1970 PROPELLANT COMBINATIONS

| Propellant Combination  | Theoretical Performance | Gravitational Acceleration (sec <sup>-2</sup> ) | Bulk Specific Gravity (sec <sup>-1</sup> ) | Gross thrust, (O/F) | Temperature, (°F) | Hypergolic Combustion |
|---|-------------------------|---|--|---------------------|-------------------|-----------------------|
| F <sub>2</sub> /N <sub>2</sub> H <sub>4</sub>   | 2.3                     | 1.51  | 363  | 422                 | 1.31              | 7550 Yes              |
| F <sub>2</sub> /N <sub>2</sub> H <sub>4</sub> + C <sub>10</sub> H <sub>16</sub> O <sub>8</sub> N <sub>2</sub> | 2.3                     | 1.51  | 362  | 420                 | 1.31              | 7500 Yes              |
| F <sub>2</sub> /RH <sub>3</sub> *   | 3.3                     | 1.46  | 359  | 419                 | 1.18              | 7370 Yes              |
| FLOX(90-10)/RMH   | 2.7                     | 1.61  | 356  | 416                 | 1.23              | 6640 Yes              |
| OF <sub>2</sub> /CH <sub>4</sub>  | 5.6                     | 1.55  | 348  | 408                 | 1.09              | 6960 No               |
| OF <sub>2</sub> /RNH <sub>2</sub> *   | 2.5                     | 1.45  | 343  | 403                 | 1.26              | 6850 Yes              |
| OF <sub>2</sub> /B <sub>2</sub> H <sub>6</sub> *  | 3.6                     | 1.04  | 365  | 433                 | 0.99              | 7440 Yes              |
| Comp. A/N <sub>2</sub> H <sub>4</sub>   | 2.7                     | 1.42  | 313  | 361                 | 1.47              | 6620 Yes              |
| Comp. A/N <sub>2</sub> H <sub>4</sub> +C <sub>10</sub> H <sub>16</sub> O <sub>8</sub> N <sub>2</sub>          | 2.7                     | 1.42  | 312  | 360                 | 1.47              | 6590 Yes              |

\* Fuel Alternatives

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~~CANDIDATE~~  
ADVANCED APOLLO

1975 PROPELLANT COMBINATIONS

| Propellant Combination                       | Height Mixture Ratio (O/F) | Volume Mixture Ratio (O/F) | Theoretical Performance | Gravitational Acceleration (sec.) | Temperature (°C) | Combustion Temperature (°F) | Hypergolic Combustion |
|--|----------------------------|----------------------------|-------------------------|-----------------------------------|------------------|-----------------------------|-----------------------|
| * $\text{F}_2/\text{N}_2\text{H}_4$          | 2.3                        | 1.51                       | 363                     | 422                               | 1.31             | 7550                        | Yes                   |
| $\text{F}_2/\text{H}_2$                      | 8.0                        | 0.37                       | 410                     | 474                               | 0.46             | 6670                        | Yes                   |
| $\text{O}_2/\text{C}_2\text{H}_5\text{NO}_2$ | 3.8                        | 2.04                       | 354                     | 422                               | 1.30             | 4990                        | Yes                   |
| $\text{F}_2/\text{BeH}_2$                    | 5.0                        | -                          | (376)                   | 440                               | 1.24             | 8790                        | Yes                   |
| $\text{O}_2/\text{H}_2+\text{Be}$            | 0.85                       | -                          | 457                     | 553                               | 0.25             | 4540                        | Yes                   |
| $\text{F}_2/\text{NHH+BeH}_2$                | 3.35                       | -                          | 363                     | ~434                              | 1.25             | 8290                        | Yes                   |

\* Possible Candidate

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PHASE I PROPELLANT SELECTION

The Phase I (1970) propellant combination candidates were studied in detail. Propulsion systems using these candidates were defined and pertinent areas such as thrust chamber cooling, feed systems, parameter selection and propellant storage were investigated. Increases in landed payload capability of the individual stages were determined. In all of these investigations the capability of the candidate propellant combinations were compared and any advantages or disadvantages noted. The results of these investigations were incorporated into the overall propulsion system analysis.

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**TASK II**

**PROPELLANT SELECTION**

**1970 CANDIDATES**

Detailed Propulsion System Analyses to  
Determine the 1970 Candidate Best Suited  
for a High Performance Apollo System

**PROPELLANT SELECTION 1970**

**Object**

1. Preliminary Analysis of Apollo with each Propellant

2. Select Outstanding Propellant Combination

**Areas Considered**

1. Feed Systems
2. Thrust Chamber Cooling
3. Propellant Storage
4. Ignition and Start
5. Parameter Selection
6. Payload Capability

## FED SYSTEM COMPARISON

Purpose:  
Compare Relative Payload  
Capability of Pump and  
Tank-pressurized Feed Systems

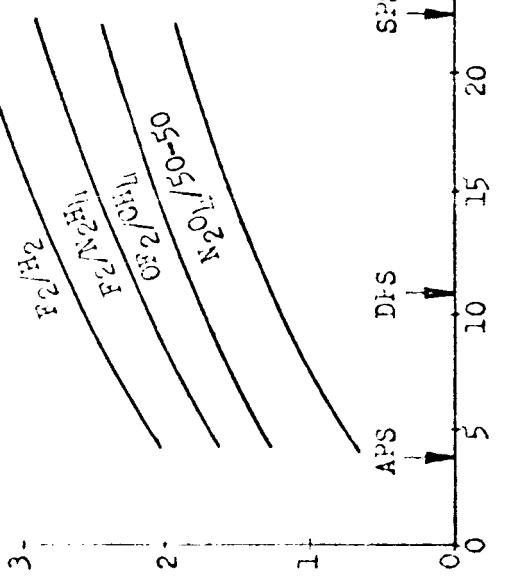
### Assumptions:

1.  $F/W = 0.3$
2.  $\Delta V = 7000 \text{ fpm}$
3. Tank Pressurization  
Method:  
Propellant Heated  $H_2$

### Conclusion:

Max 3% Increase for Pump-fed  
 $F_2/H_2$  Highest Gain  
 $F_2/H_2$  Pump-fed System to be  
investigated for Phase II  
(1975) effort

Pump-Fed System      Percentage Payload Increase



Thrust, K

## PRESSURIZATION SYSTEM COMPARISONS

- SYSTEMS CONSIDERED:

- UNHEATED
  - HEAT EXCHANGER - INDIVIDUAL PROPELLANTS
  - HEAT EXCHANGER - HOTTER PROPELLANTS
  - HEAT EXCHANGER - TRUST CHAMBER
- PRESENT SYSTEM: HEAT EXCHANGER - INDIVIDUAL PROPELLANTS

SERVICE MODULE/PRESSURIZATION SYSTEM

Multi-Phase Mission  
 Helium Pressurant  
 Storage Bottle at Temperature of Colder Propellant  
 Safety Factor of 1.3 on Amount of Helium

| Propellant                        | Relative System Weight    |   |                                       |                                    |
|-----------------------------------|---------------------------|---|---------------------------------------|------------------------------------|
|                                   | Unheated;<br>Single Phase | Individual<br>Propellant<br>Heat $\times$ | Hotter<br>Propellant<br>Heat $\times$ | Thrust<br>Chamber<br>Heat $\times$ |
| $\text{F}_2/\text{N}_2\text{H}_4$ | 1.81                      | 1.33                                      | 1.03                                  | 1.0                                |
| $\text{FLOX(90)}/\text{MNH}$      | 2.48                      | 1.35                                      | 1.02                                  | 1.0                                |
| $\text{OF}_2/\text{CH}_4$         | 1.69                      | 1.16                                      | 1.16                                  | 1.0                                |
| Comp A/ $\text{N}_2\text{H}_4$    | 1.54                      | 1.018                                     | 1.018                                 | 1.0                                |

DESCENT MODULE/PRESSURIZATION SYSTEM

Single - Phase Mission  
 Helium Pressurant  
 Storage Bottle at Temperature of Colder Propellant  
 Safety Factor of 1.3 on Amount of Helium

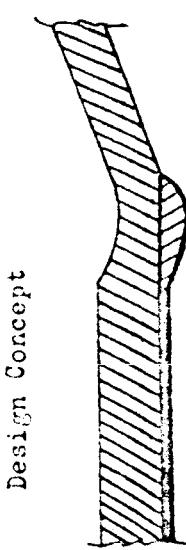
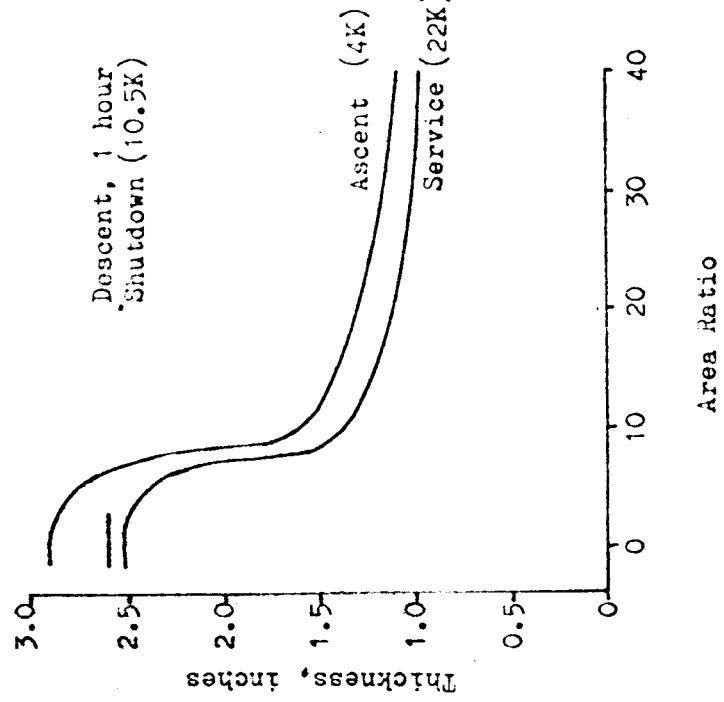
| Propellant                        | Unheated | Relative System Weight              |                                 |                              |
|-----------------------------------|----------|-------------------------------------|---------------------------------|------------------------------|
|                                   |          | Individual Propellant Heat $\times$ | Hotter Propellant Heat $\times$ | Thrust Chamber Heat $\times$ |
| $\text{F}_2/\text{N}_2\text{H}_4$ | 5.8      | 3.09                                | 1.24                            | 1.0                          |
| FLOX(90)/MMH                      | 5.8      | 3.12                                | 1.245                           | 1.0                          |
| $\text{OF}_2/\text{CH}_4$         | 2.69     | 1.84                                | 1.84                            | 1.0                          |
| Comp A/ $\text{N}_2\text{H}_4$    | 2.22     | 1.49                                | 1.24                            | 1.0                          |

THRUST CHAMBER COOLING ANALYSES

- METHODS CONSIDERED:
  - ABLATIVE
  - REGENERATIVE
  - RADIATIVE (NOZZLE SKIRT)
- ABLATIVE DESIGN FLIGHT DURATION PLUS ACCEPTANCE TESTING
- RADIATIVE NOZZLE SKIRT NOT USED FOR LEM ASCENT STAGE

## ABLATIVE THRUST CHAMBER DESIGN

Conditions  
Propellant:  $\text{F}_2/\text{N}_2\text{H}_4$   
Pressure: 150 psia  
Max. Wall Temperature: 400F



1. Pyrographite Throat Insert
2. 0.5 inches of phenolic impregnated, graphite cloth
3. Phenolic refrasil Backing

## REGENERATIVE THRUST CHAMBER COOLING

Chamber Pressure = 150 psia

Pressure Drop/Chamber Pressure

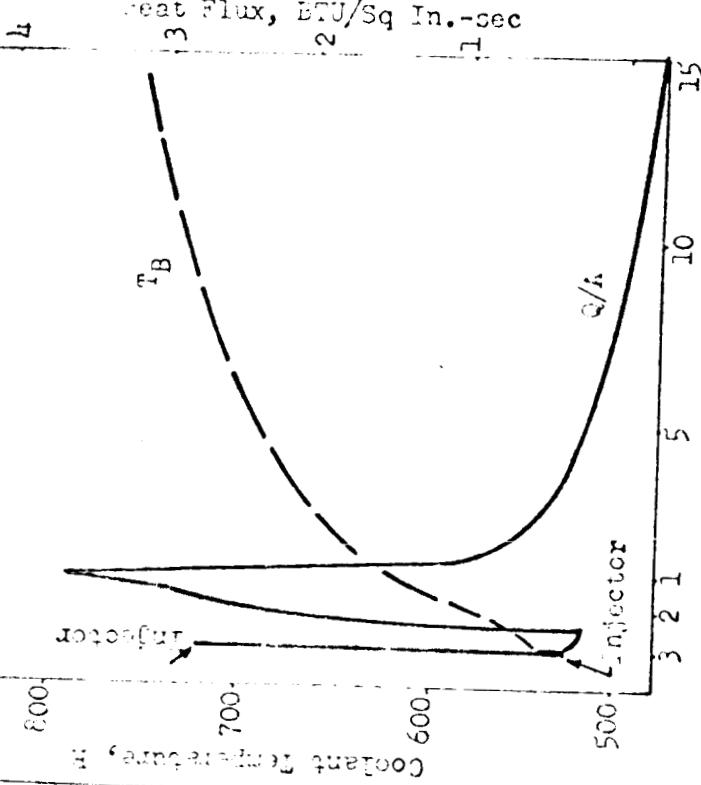
| Propellant Combination            | 22K<br>(Service) | 10.5K<br>(Descent) | 4K<br>(Ascent) |
|-----------------------------------|------------------|--------------------|----------------|
| $\text{F}_2/\text{N}_2\text{H}_4$ | < 0.10           | 0.28               | -              |
| FLOX(90)/MNH                      | 0.92(0.13)*      | 3(0.8)*            | 7.3(5.1)*      |
| $\text{OF}_2/\text{CH}_4$         | 8.0              | > 8                | > 8            |
| Comp A/ $\text{N}_2\text{H}_4$    | < 0.10           | ~ 0.10             | 0.3            |

\* MNH is prechilled to -60F

REGENERATIVE COOLING ANALYSIS

$F_2/N_2H_4$        $F = 22,000$  pounds

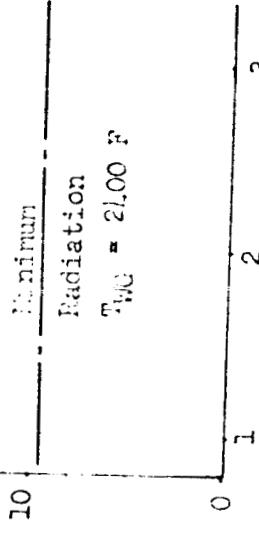
Chamber Pressure = 150 psia  
Mixture Ratio = 2.3



Chamber Pressure = 100 psia

Maximum  
Regenerative  
 $T_B = 300$  F

Heat Flux, BTU/Sq In.-sec  
Nozzles Area Ratio



Mixture Ratio

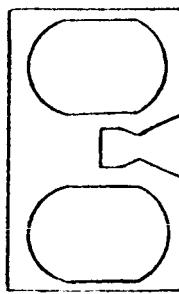
$T_{BG} = 21.00$  F

Nozzles Area Ratio

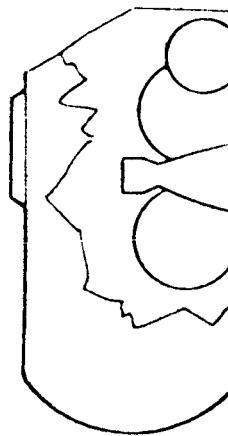
RADIATIVE THRUST CHAMBER SKIRT



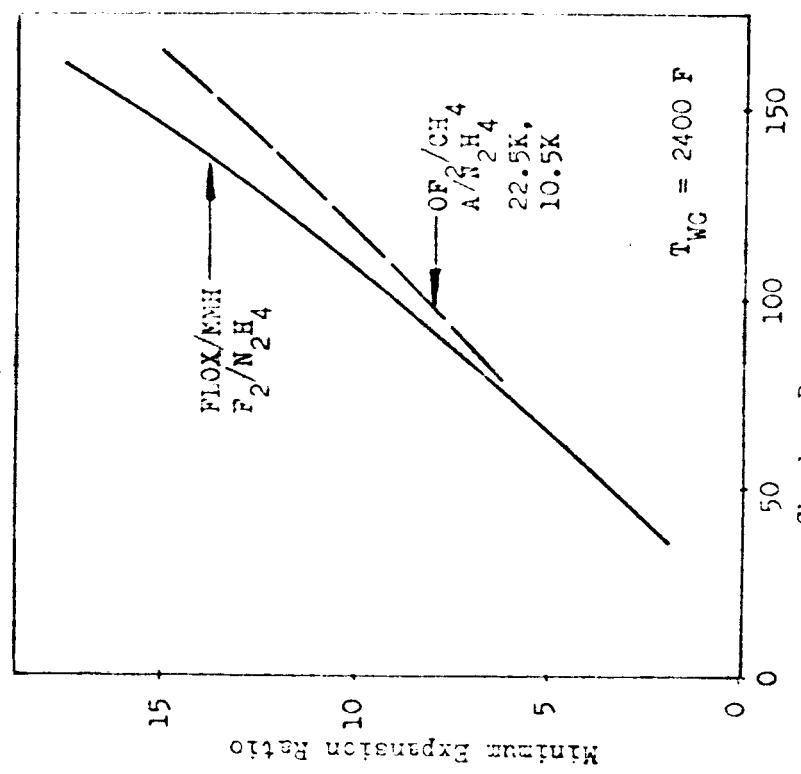
Service Module



Descent System



Ascent System



Minimum Area Ratio vs Chamber Pressure  
Radiation Cooled Skirt  
Shape Factor = 1.0, Emissivity = 0.9

THRUST CHAMBER

COOLING COMPARISON, F<sub>2</sub> / N<sub>2</sub>H<sub>4</sub>

|  | <u>Regenerative</u>  | <u>Ablative</u>   |
|--|--|---|
| Landed Payload Increase,<br>pounds (SPS) | 4330   | 4050  |
| Advantages:                              | <ul style="list-style-type: none"><li>1. Higher Payload</li><li>2. Dimensional Stability</li></ul> | <ul style="list-style-type: none"><li>1. Short Lead Time</li><li>2. No Area Ratio Limit</li><li>3. No Throttling Problems</li></ul> |
| Propulsion System:                       | SPS, DPS   | SPS, DPS, APS   |

IGNITION METHOD

Required Starts

SFS - 13

DPS - 3

APS - 3

Start Method

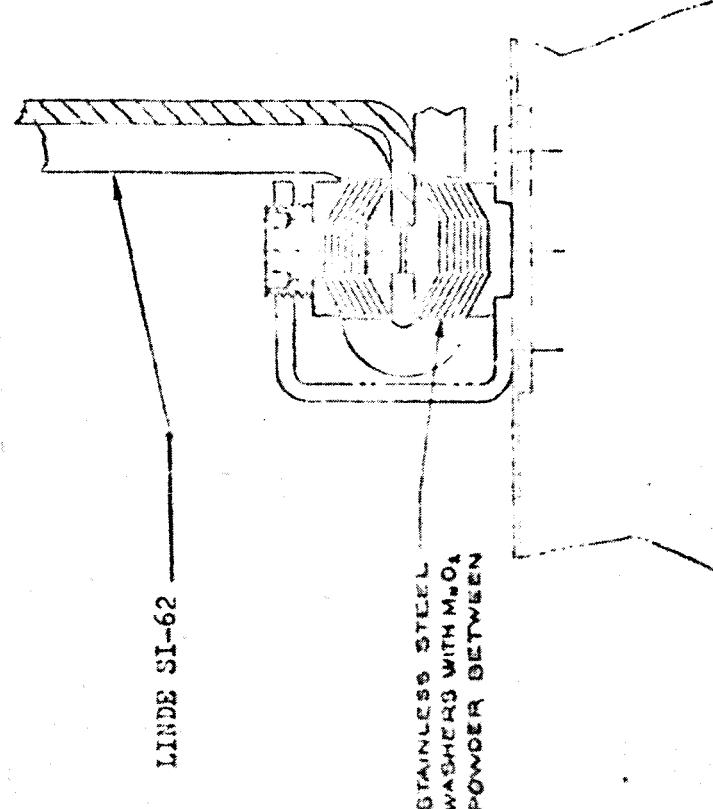
| <u>Propellant</u>                      | <u>Method</u>       | <u>Relative Subsystem</u> | <u>Unreliability</u>     | <u>Comment</u> |
|--|---------------------|---------------------------|--------------------------|----------------|
| F2/N <sub>2</sub> H <sub>4</sub>       | Hypergolic          | 1.0                       |                          |                |
| FLOX(90)/N <sub>2</sub> H <sub>4</sub> | Hypergolic          | 1.0                       |                          |                |
| Comp A/N <sub>2</sub> H <sub>4</sub>   | Hypergolic          | 1.0                       |                          |                |
| CF <sub>2</sub> /CH <sub>4</sub>       | Hypergolic Additive | 1.0                       | None in Existence        |                |
|  | Spark Igniter       | 1.07                      |                          |                |
|  | Catalytic Ignition  | 1.10                      | Low State of Development |                |

## SPACE STORAGE OF PROPELLANTS

- Requirements

1. Time-Two Weeks
2. No Venting
3. Upper Limit-Max. Vapor Pressure
4. Lower Limit-Freezing Point

- Design Concept



- Insulation Requirements

1. Thickness  
1/8" to 1/4"
2. Weight, 1b  
SPS 28 - 65  
DPS 14 - 35  
APS 5 - 13
3. Ullage  
Approximately 3%

## THROTTLING METHOD SELECTION - NIPS

### • Requirements

Thrust Variation                    10:1  
Main Maneuver Duration            44.5 seconds  
Throttled Maneuver Duration      120 seconds

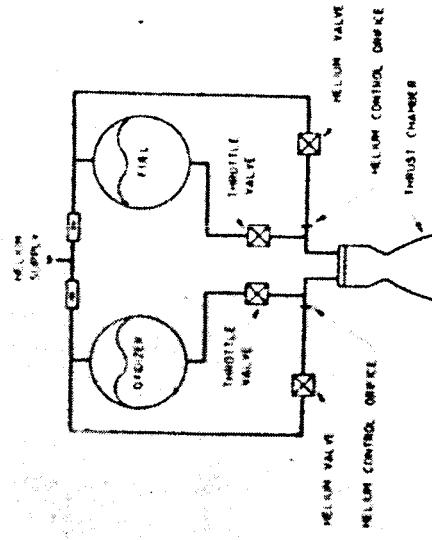
### • Comparison

| <u>Method</u>            | <u>Performance Loss</u>            | <u>Relative Failure Rate</u> | <u>Stability</u> |
|--------------------------|------------------------------------|------------------------------|------------------|
| Valve-In-Line            | Throttled Operation                | 0.000                        | Poor             |
| Injector Area Variation  | Main Operation                     | 0.0020                       | Good             |
| Helium Injection         | Slight; During Throttled Condition | 0.00001                      | Good             |
| Concentric Tube Injector | Slight; During Throttled Condition | 0.0004                       | Good             |

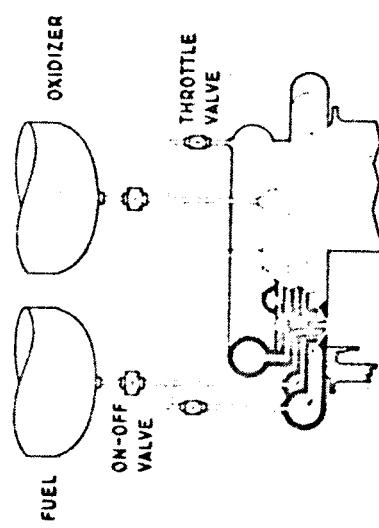
### • Conclusions

1. No Discernable Differences Between Propellants
2. Use Helium Injection or Concentric Tube Injector

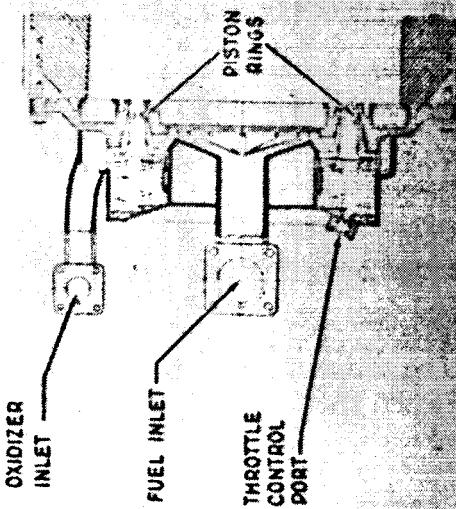
# THROTTLING



**He THROTTLING SCHEMATIC**



**VARIABLE AREA INJECTOR SCHEMATIC**



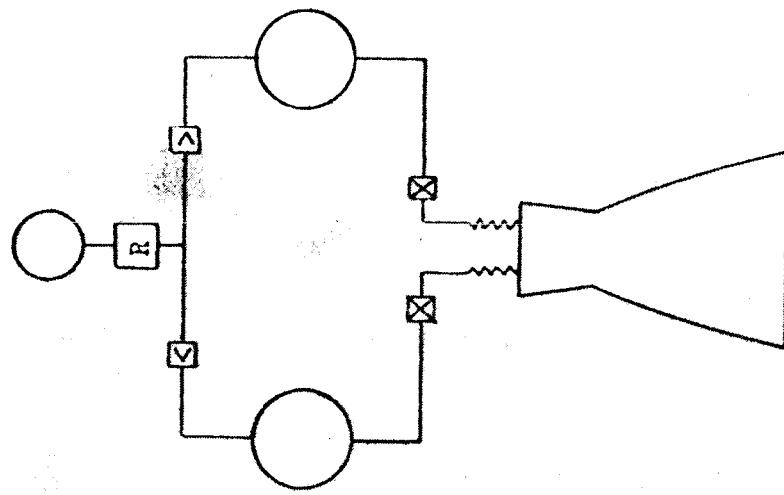
**MOM. EXCH SCHEMATIC**

12

MATERIALS COMPATIBILITY

|                  |           | H <sub>2</sub> | B <sub>2</sub> H <sub>6</sub> | CH <sub>4</sub> | NH <sub>3</sub> | N <sub>2</sub> H <sub>4</sub> | O <sub>2</sub> | N <sub>2</sub> P <sub>4</sub> | Comp. A | HLOX(90-10) | H <sub>2</sub> |               |
|------------------|-----------|----------------|-------------------------------|-----------------|-----------------|-------------------------------|----------------|-------------------------------|---------|-------------|----------------|---------------|
|                  | Metallics |                |                               |                 |                 |                               |                |                               |         |             |                | Non-Metallics |
| Stainless Steels | x         | x              | x                             | x               | x               | x                             | x              | x                             | x       | x           | x              |               |
| Aluminum         | x         | x              | x                             | x               | x               | x                             | x              | x                             | x       | x           | x              |               |
| Titanium         | x         | x              | x                             | x               | x               | x                             | x              | x                             | x       | x           | x              |               |
| Copper           | x         | x              | x                             | x               | x               | x                             | x              | x                             | x       | x           | x              |               |
| Nickel           | x         | x              | x                             | x               | x               | x                             | x              | x                             | x       | x           | x              |               |
| K-monel          | x         | x              | x                             | x               | x               | x                             | x              | x                             | x       | x           | x              |               |
| Inconel          | x         | x              | x                             | x               | x               | x                             | x              | x                             | x       | x           | x              |               |
| Brass            | x         | x              | x                             | x               | x               | x                             | x              | x                             | x       | x           | x              |               |
| Lead             | x         | x              | x                             | x               | x               | x                             | x              | x                             | x       | x           | x              |               |
|                  |           |                |                               |                 |                 |                               |                |                               |         |             |                |               |
| Asbestos         |           | x              | x                             | x               | x               | x                             | x              | x                             | x       | x           | x              |               |
| Graphite         |           | x              | x                             | x               | x               | x                             | x              | x                             | x       | x           | x              |               |
| Glass            |           | x              | x                             | x               | x               | x                             | x              | x                             | x       | x           | x              |               |
| Teflon           |           | x              | x                             | x               | x               | x                             | x              | x                             | x       | x           | x              |               |
| Kel F            |           | x              | x                             | x               | x               | x                             | x              | x                             | x       | x           | x              |               |
| Neoprene         |           | x              | x                             | x               | x               | x                             | x              | x                             | x       | x           | x              |               |
| Boron Carbide    | x         | x              | x                             | x               | x               | x                             | x              | x                             | x       | x           | x              |               |
| Rubber           |           |                |                               |                 |                 |                               |                |                               |         |             |                |               |

$\text{F}_2/\text{N}_2\text{H}_4$  SYSTEM MATERIALS BASED ON G-1 SYSTEM



| <u>PROPELLANT COMBINATION</u> | <u>EFFECT ON RELIABILITY</u> | <u>Propellant Combination Differences</u>  |
|-------------------------------|------------------------------|--|
| <u>Component or Subsystem</u> |                              |  |
| Pressurization System         |                              | Propellant Heat Exchangers                 |
| Propellant Storage System     | None                         |  |
| Flow Control System           | None                         |  |
| Thrust Chamber                | None                         |  |
| Irrition System               |                              | $\text{OF}_2/\text{CH}_4$ is nonhypergolic |

- Comparison

- Conclusion:

1.  $\text{OF}_2/\text{CH}_4$  system has lowest reliability
2. Other systems have essentially the same reliability

## OPERATING PARAMETER SELECTION GROUND RULES

### ● Basis - Maximize Landed Payload

#### ● Parameters Considered

1. Thrust
2. Chamber Pressure
3. Mixture Ratio
4. Expansion Ratio

#### ● Envelope Restrictions

##### 1. Nozzle Exit Diameter

SPS - 100 in.

DPS - 50 in.

APS - 32 in.

##### 2. Propellant Tank Dimensions

SPS L < 166 inches

DPS D < 55 inches

APS D < 40 inches

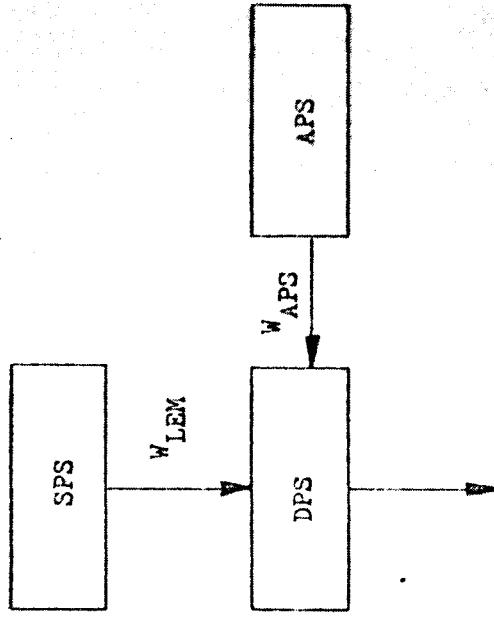
#### ● Assumptions

1. Ablative Cooling
2. Cold Helium Pressurization
3. Aluminum Oxidizer tanks
- Titanium Fuel tanks
4. Bray Performance except for Fluordyne ( $A/N_2H_4$ )

Lunar  
Landed  
Payload

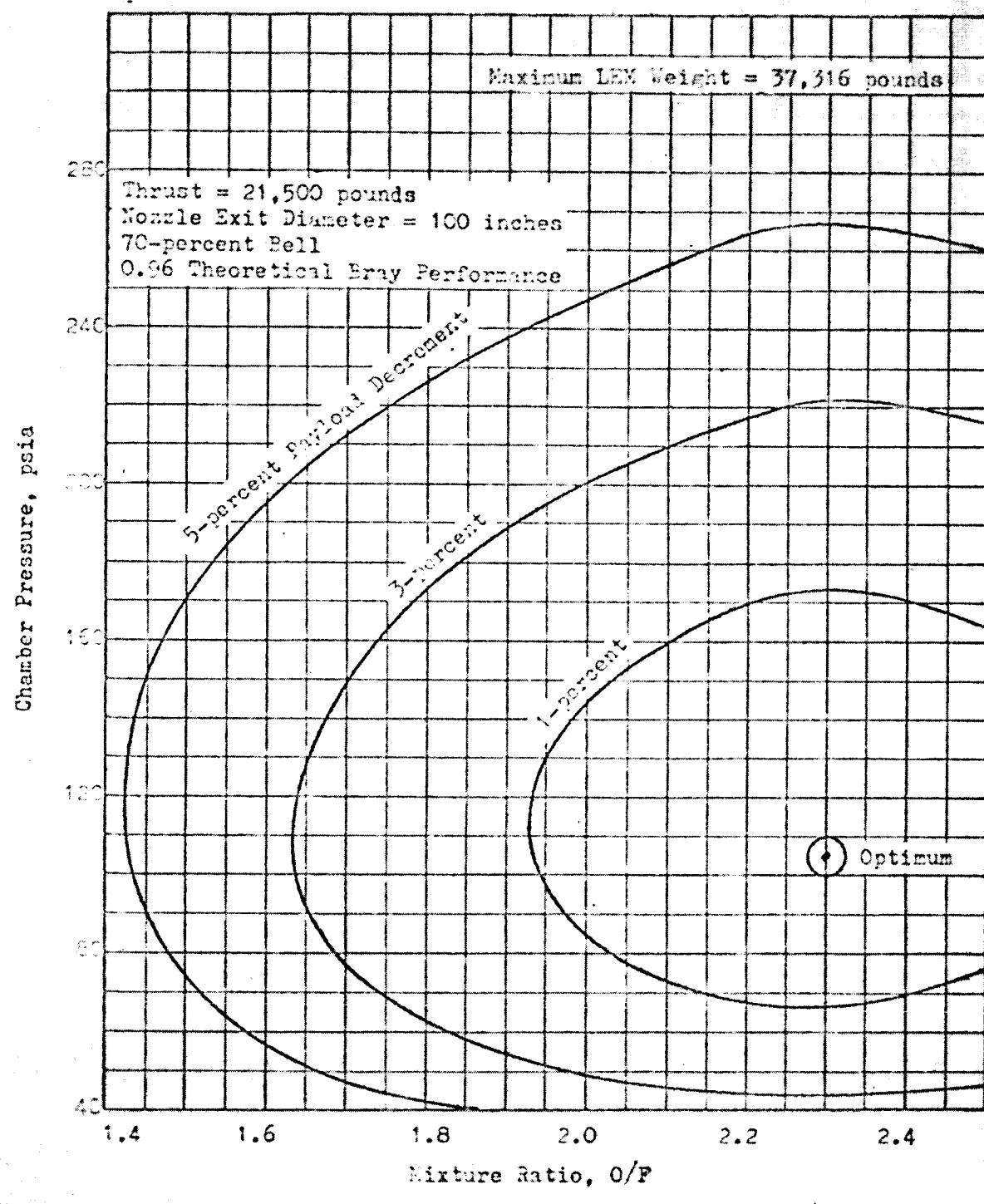
#### ● Landed Payload Calculation

Apollo System = 90,000 lbs



**OPTIMUM DESIGN PARAMETERS**  
 Nominal Thrust Level  
 Ablative Thrust Chamber

| Propulsion System | Propellant Combination                        | Chamber Pressure, psia | Mixture Ratio, O/F | Expansion Ratio (Restricted) |
|-------------------|---|------------------------|--------------------|------------------------------|
| SPS               | F <sub>2</sub> /N <sub>2</sub> H <sub>4</sub> | 105                    | 2.30               | 71                           |
|                   | FLOX(90)/MMH                                  | 50                     | 2.90               | 36                           |
|                   | Comp. A/N <sub>2</sub> H <sub>4</sub>         | 100                    | 2.65               | 66                           |
|                   | OF <sub>2</sub> /CH <sub>4</sub>              | 70                     | 4.90               | 45                           |
| DP3               | F <sub>2</sub> /N <sub>2</sub> H <sub>4</sub> | 120                    | 2.30               | 44                           |
|                   | FLOX(90)/MMH                                  | 70                     | 2.80               | 25                           |
|                   | Comp A/N <sub>2</sub> H <sub>4</sub>          | 120                    | 2.60               | 1.3                          |
|                   | OF <sub>2</sub> /CH <sub>4</sub>              | 90                     | 4.90               | 32                           |
| APS               | F <sub>2</sub> /N <sub>2</sub> H <sub>4</sub> | 110                    | 2.25               | 1.0                          |
|                   | FLOX(90)/MMH                                  | 85                     | 2.70               | 30                           |
|                   | Comp A/N <sub>2</sub> H <sub>4</sub>          | 120                    | 2.60               | 43                           |
|                   | OF <sub>2</sub> /CH <sub>4</sub>              | 82                     | 3.72               | 28                           |



SPS Payload Contours,  $F_2/N_2H_4$  Pressure-Fed System

THRUST CHAMBER  
COOLING COMPARISON, F<sub>2</sub> / N<sub>2</sub>H<sub>4</sub>

|  | <u>Regenerative</u>  | <u>Ablative</u>   |
|--|--|---|
| Landed Payload Increase,<br>pounds (SPS) | 4330   | 4050  |
| Advantages:                              | <ul style="list-style-type: none"><li>1. Higher Payload</li><li>2. Dimensional Stability</li></ul> | <ul style="list-style-type: none"><li>1. Short Lead Time</li><li>2. No Area Ratio Limit</li><li>3. No Throttling Problems</li></ul> |
| Propulsion System:                       | SPS, DPS   | SPS, DPS, APS   |

## IGNITION METHOD

### Required Starts

SFS - 13

DPS - 3

APS - 3

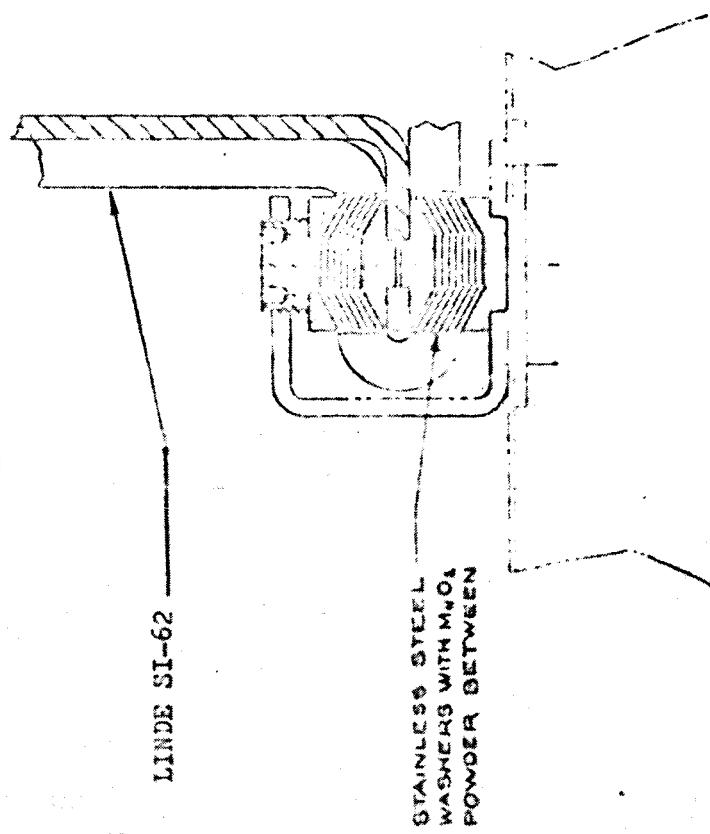
### Start Method

| <u>Propellant</u> | <u>Method</u>       | <u>Relative Subsystem</u> | <u>Unreliability</u>     | <u>Comment</u> |
|-------------------|---------------------|---------------------------|--------------------------|----------------|
| F2/N2H4           | Hypergolic          | 1.0                       |                          |                |
| FLOX(90)/N2H      | Hypergolic          | 1.0                       |                          |                |
| Comp A/N2H4       | Hypergolic          | 1.0                       |                          |                |
| CF2/CH4           | Hypergolic Additive | 1.0                       | None in Existence        |                |
|                   | Spark Igniter       | 1.07                      |                          |                |
|                   | Catalytic Ignition  | 1.10                      | Low State of Development |                |

## SPACE STORAGE OF PROPELLANTS

- Requirements
  - 1. Time-Two Weeks
  - 2. No Venting
  - 3. Upper Limit-Max. Vapor Pressure
  - 4. Lower Limit-Freezing Point

### ● Design Concept



### ● Insulation Requirements

- 1. Thickness  
1/8" to 1/4"
- 2. Weight, lb  
SPS 28 - 65  
DPS 14 - 35  
APS 5 - 13
- 3. Ullage  
Approximately 3 %

## THROTTLING METHOD SELECTION - PPS

### ● Requirements

Thrust Variation                    10:1  
Main Maneuver Duration            4.5 seconds  
Throttled Maneuver Duration      120 seconds

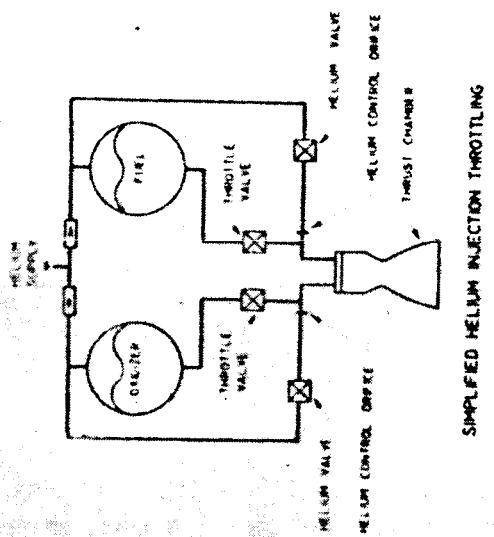
### ● Comparison

| <u>Method</u>            | <u>Performance Loss</u>            | <u>Relative Failure Rate</u> | <u>Stability</u> |
|--------------------------|------------------------------------|------------------------------|------------------|
| Valve-In-Line            | Throttled Operation                | 0.000                        | Poor             |
| Injector Area Variation  | Main Operation                     | 0.0020                       | Good             |
| Helium Injection         | Slight; During Throttled Condition | 0.0004                       | Good             |
| Concentric Tube Injector | Slight; During Throttled Condition | 0.0004                       | Good             |

### ● Conclusions

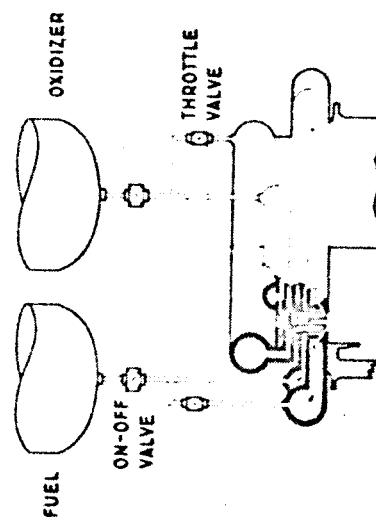
1. No Discernable Differences Between Propellants
2. Use Helium Injection or Concentric Tube Injector

# THROTTLING

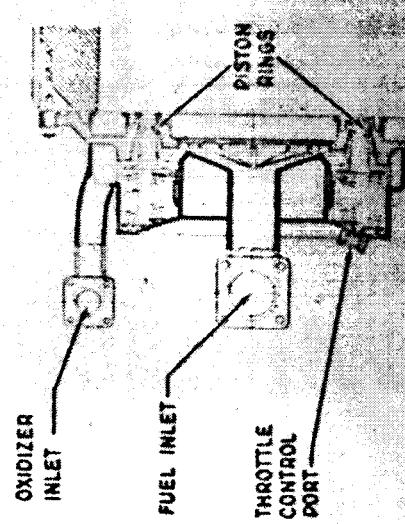


He THROTTLING SCHEMATIC

VARIABLE AREA INJECTOR SCHEMATIC



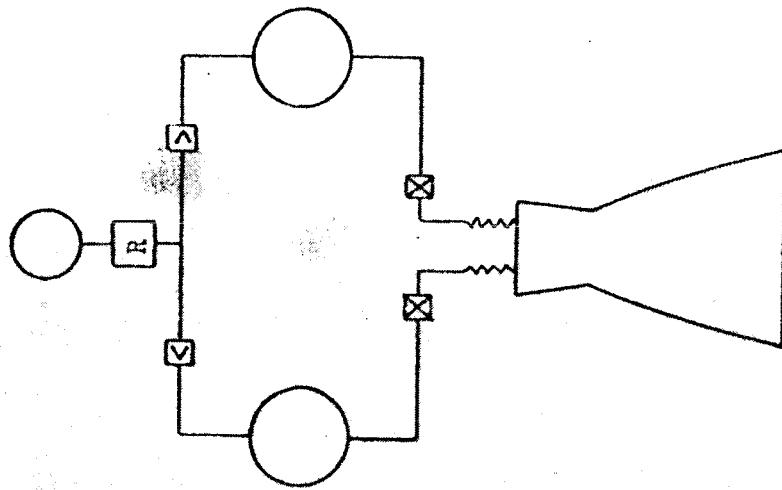
MOM. EXCH SCHEMATIC



MATERIALS COMPATIBILITY

|                      | F <sub>2</sub> | OF <sub>2</sub> | O <sub>2</sub> F <sub>4</sub> | N <sub>2</sub> H <sub>4</sub> | NH <sub>3</sub> | NH <sub>2</sub> H <sub>3</sub> | CH <sub>4</sub> | B <sub>2</sub> H <sub>6</sub> | E <sub>2</sub> |
|----------------------|----------------|-----------------|-------------------------------|-------------------------------|-----------------|--------------------------------|-----------------|-------------------------------|----------------|
| <u>Metallics</u>     |                |                 |                               |                               |                 |                                |                 |                               |                |
| Stainless Steels     | x              | x               | x                             | x                             | x               | x                              | x               | x                             | x              |
| Aluminum             | x              | x               | x                             | x                             | x               | x                              | x               | x                             | x              |
| Titanium             | x              | x               | x                             | x                             | x               | x                              | x               | x                             | x              |
| Copper               | x              | x               | x                             | x                             | x               | x                              | x               | x                             | x              |
| Nickel               | x              | x               | x                             | x                             | x               | x                              | x               | x                             | x              |
| K-monel              | x              | x               | x                             | x                             | x               | x                              | x               | x                             | x              |
| Inconel              | x              | x               | x                             | x                             | x               | x                              | x               | x                             | x              |
| Brass                | x              | x               | x                             | x                             | x               | x                              | x               | x                             | x              |
| Lead                 | x              | x               | x                             | x                             | x               | x                              | x               | x                             | x              |
| <u>Non-Metallics</u> |                |                 |                               |                               |                 |                                |                 |                               |                |
| Asbestos             |                |                 |                               | x                             | x               | x                              | x               | x                             | x              |
| Graphite             |                |                 | x                             | x                             | x               | x                              | x               | x                             | x              |
| Glass                |                |                 | x                             | x                             | x               | x                              | x               | x                             | x              |
| Teflon               |                |                 | x                             | x                             | x               | x                              | x               | x                             | x              |
| Kel F                |                |                 | x                             | x                             | x               | x                              | x               | x                             | x              |
| Neoprene             |                |                 | x                             | x                             | x               | x                              | x               | x                             | x              |
| Boron Carbide        | x              | x               | x                             | x                             | x               | x                              | x               | x                             | x              |
| Rubber               |                |                 |                               |                               |                 |                                |                 |                               |                |

$\text{F}_2/\text{N}_2\text{H}_4$  SYSTEM MATERIALS BASED ON G-1 SYSTEM.



Tanks - Al 6061

Ducting - Stainless Steel 347

Oxidizer Valve - (1) Stainless Steel 321  
(2) Poppet is Nickel Plated  
(3) Metal-to-Metal Seal

Oxidizer Bellows - Stainless Steel

Injector - Al 6061

Thrust Chamber - Stainless Steel

PROPELLANT COMBINATION

| <u>EFFECT</u> | <u>ON RELIABILITY</u> |
|---------------|-----------------------|
|---------------|-----------------------|

- Comparison

| <u>Component or Subsystem</u> | <u>Propellant Combination Differences</u>  |
|-------------------------------|--|
| Pressurization System         | Propellant Heat Exchangers                 |
| Propellant Storage System     | None                                       |
| Flow Control System           | None                                       |
| Thrust Chamber                | None                                       |
| Ignition System               | $\text{OF}_2/\text{CH}_4$ is nonhypertolic |

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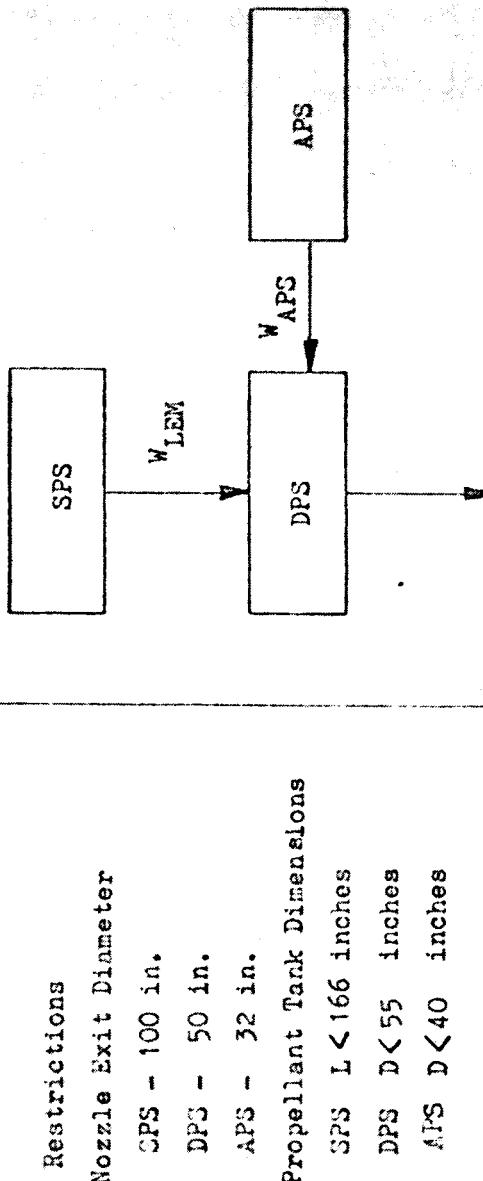
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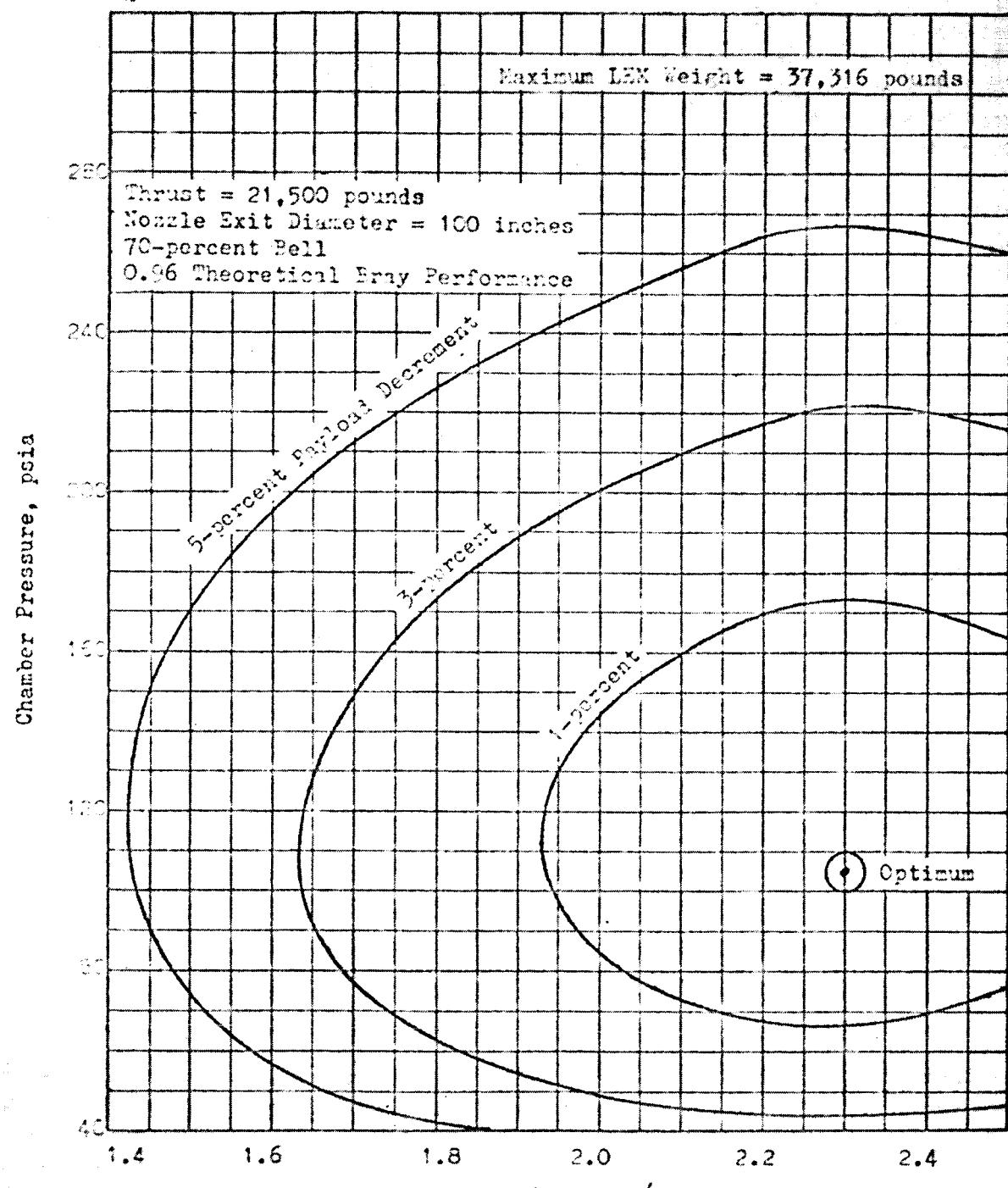
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